

**Respiration, Ethylene Production,
and Shelf Life Extension
in Irradiated Papaya Fruit After Storage
Under Simulated Shipping Conditions**

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INTRODUCTION

The effectiveness of ionizing irradiation with gamma rays to extend the shelf life of fresh fruit of the papaya (*Carica papaya* L. 'Solo') has been demonstrated (4,5,6,7), and the relationship between shelf life extension and respiration has also been investigated (3). This technical bulletin reports the relationship between irradiation, shelf life, respiration, and ethylene production of papaya fruit after storage under conditions simulating air and surface shipment from Hawaii to the United States Mainland.

MATERIALS AND METHODS

Freshly harvested papaya fruits from the Island of Hawaii were air-flown to Honolulu, Island of Oahu, where they were installed in experiments on the afternoon of the day of harvest. To control storage decay, all fruits were dipped for 20 minutes in hot water maintained at 120° F, and then they were cooled in running tap water for 20 minutes (1,2,4,5,6,7). The fruits were then irradiated with gamma rays from a Cobalt⁶⁰ source at the Hawaii Research Irradiator facility. Each experiment used fruits of uniform maturity as judged visually by the approxi-

mate degree of surface yellow color development. For the determination of respiration and ethylene production, four replicate fruits were used in each treatment.

After treatment, the fruits were stored under two sets of temperature conditions to approximately simulate shipping conditions to the U.S. Mainland from Hawaii: (1) without refrigeration at 77° F for 1 day to simulate air-shipping conditions and (2) with refrigeration at 55° F for 7 days to simulate marine-shipping conditions. For the first lot, initial gas sampling was performed just prior to the 1-day storage period and then daily thereafter at 77° F. For the second lot, initial gas sampling was performed when the fruits were removed from refrigeration and then daily thereafter at 70–77° F.

For each treatment, samples of carbon dioxide (CO₂) for respiration measurements and ethylene (C₂H₄) were taken from the atmospheres around four fruits held separately for 1 hour in sealed gastight glass jars (volume about 6.2 liters). Gas samples of 1 to 5 milliliters were withdrawn with a gastight syringe from each jar for analysis by gas chromatography, using a thermal conductivity detector unit (Varian Aerograph 90-P) for CO₂ and a hydrogen flame ionization unit (Aerograph Hy-Fi 600-D) for C₂H₄. The thermal conductivity detector unit was equipped with a silica gel (powder) column in a copper tubing (internal diameter ¼ inch, length 14 inches). The respective temperatures for the column, injector, and detector were 210°, 250°, and 235° F. The carrier gas was helium maintained at a flow rate of 47 ml/minute. The hydrogen flame ionization unit was equipped with an alumina (60/80 screen size) column in an aluminum tubing (internal diameter 1/8 inch, length 6 feet). The respective temperatures for the column and injector were 212° and 265° F. The flow rate of the carrier gas (nitrogen) and the hydrogen was 25 ml/minute. The average analyses from the four replicates in each treatment are shown in the plots of results (Figures 1–7).

Between gas samplings, the fruits were held in open corrugated paper papaya cartons at temperatures used for the CO₂ and C₂H₄ determinations. The rate of ripening and the time of the attainment of the edible ripe stage were also observed. A fruit was considered edible ripe when the surface was about 87 percent yellowed and yielded slightly or readily to finger pressure. Observations were continued until the fruits were judged unmarketable due to decay or overripening (fruit yielded very readily to finger pressure), or both.

RESULTS

Unrefrigerated Fruit

In a series of four experiments, fruits irradiated at 25-28.5, 75-85.5, 125-142.5, or 250-285 krad were studied at 77° F, a temperature favorable for ripening.

In the first experiment, fruits with an initial degree of surface yellowing of approximately 13 percent were irradiated at 25-28.5 krad.

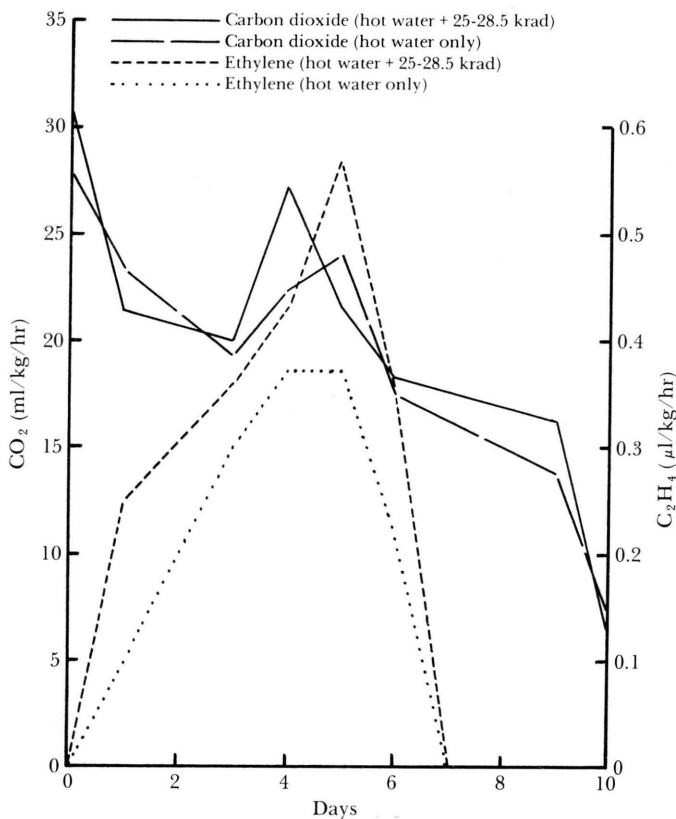


Figure 1. Respiration (CO₂) and ethylene (C₂H₄) production in 13 percent yellow papayas hot water treated only or hot water treated and irradiated at 25-28.5 krad, followed by storage at 77° F.

The results for irradiated and unirradiated fruits are shown in Figure 1. The initial high rates of respiration were due to the high temperature (about 85–90° F) of the fruits immediately after the hot-water dip and irradiation. Fruit temperature decreased to the temperature (77° F) of the storage room by the following day, and respiration also decreased. Respiration continued to decrease during days 2 and 3, then it began to increase. The respiratory peak for the irradiated lot was attained on day 4 and was slightly greater than that of the unirradiated lot, which reached its peak on day 5. In general, the respiratory patterns of the two lots were similar. The fruits attained the edible ripe stage in 4 to 5 days. Immediately after treatment, no C_2H_4 production was detected in either lot of fruits (Figure 1). In contrast to respiration and despite a reduction in fruit temperature during day 1, production of C_2H_4 in both lots commenced and continued to increase to about the time of the respiratory peak. Then a rapid decrease followed. The onset of C_2H_4 production preceded the increase in CO_2 liberation by 2 days. The production of C_2H_4 was greater in irradiated than in unirradiated fruits (Figure 1).

The results of the second, similar experiment, in which fruits with about 25 percent yellowed surface were irradiated at a dose of 75–85.5 krad, are shown in Figure 2. As in the previous experiment, no C_2H_4 emanation was detected initially in either lot. During the first day, fruit temperature decreased, C_2H_4 production began, and respiration decreased. The onset of C_2H_4 production preceded by 1 day the respiratory rise (Figure 2). The C_2H_4 production peak was attained 1 day earlier by the unirradiated lot, but the height of the peak was greater in the irradiated lot. The respiratory peak was attained on the same day. The fruits in both lots became edible ripe on the third day after treatment.

In the third experiment, fruits with about 15 percent surface yellowing were subjected to a dose of 125–142.5 krad. The results (Figure 3) indicated that respiration and C_2H_4 production were both greatly altered by irradiation at this dose. The respiratory and C_2H_4 production peaks were more than doubled in height, and the attainment of the peaks was delayed 3 or 4 days. The unirradiated lot was edible ripe in 4 days, and the irradiated lot in 7 days. The irradiated fruits developed blotchiness (uneven surface degreening) and scalding (surface browning). In this experiment, the onset of C_2H_4 production and the onset of respiratory rise coincided (Figure 3).

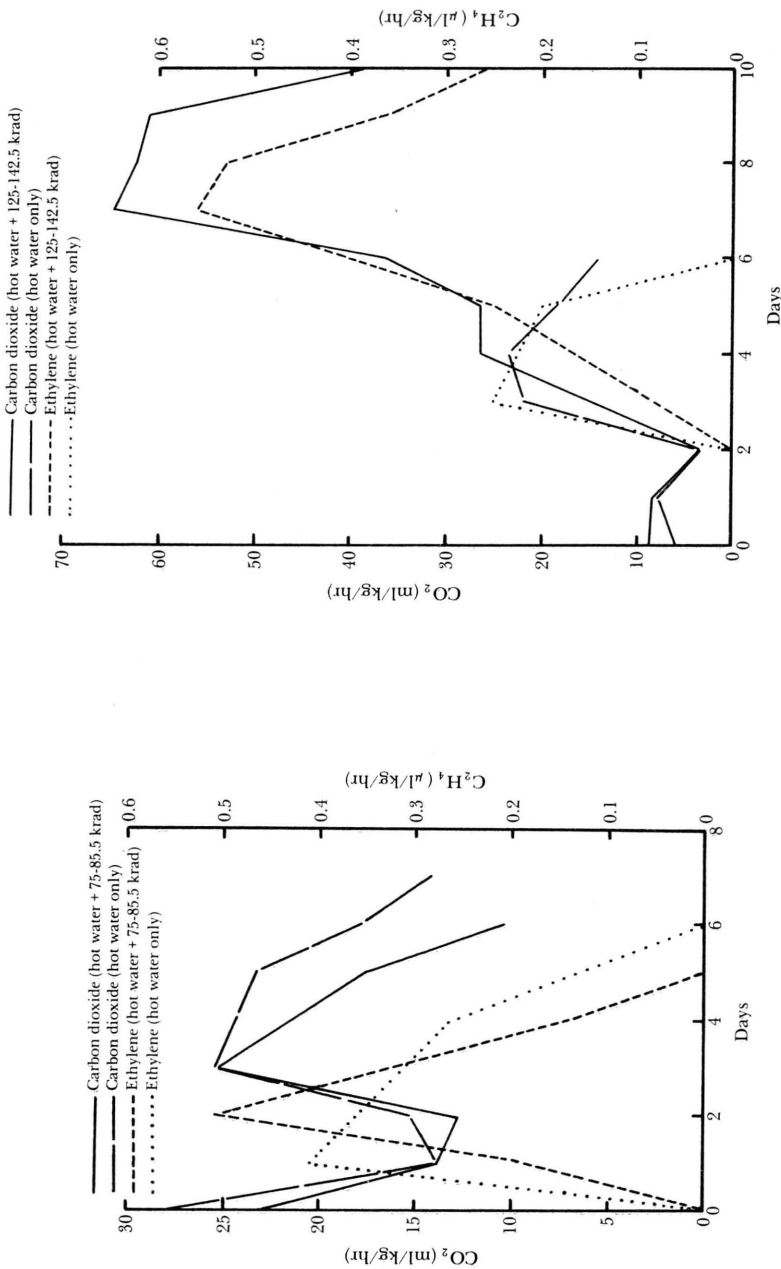


Figure 2. Respiration (CO₂) and ethylene (C₂H₄) production in 25 percent yellow papayas hot water treated only or hot water treated and irradiated at 75-85.5 krad, followed by storage at 77°F.

Figure 3. Respiration (CO₂) and ethylene (C₂H₄) production in 15 percent yellow papayas hot water treated only or hot water treated and irradiated at 125-142.5 krad, followed by storage at 77°F.

In the fourth experiment, fruits with about 13 percent surface yellowing were irradiated at a dose of 250–285 krad. An even greater effect on respiration and C_2H_4 production occurred with this higher dose (Figure 4). The respiratory peak was increased four times by irradiation, and the attainment of the peak was delayed 2 days. The C_2H_4 peak was increased five times, and the attainment of the peak was delayed 2 days by irradiation. The unirradiated fruits were edible

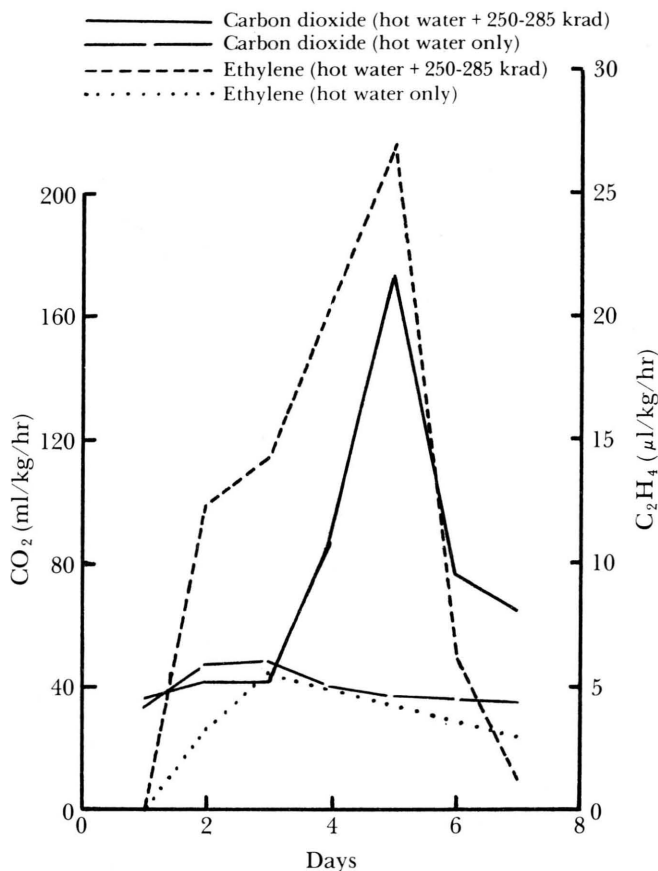


Figure 4. Respiration (CO_2) and ethylene (C_2H_4) production in 13 percent yellow papayas hot water treated only or hot water treated and irradiated at 250-285 krad, followed by storage at 77° F.

ripe in 3 days. The irradiated fruits, on the other hand, were severely scalded and failed to ripen, remaining firm throughout the storage period until attacked by decay organisms. There was again a simultaneous onset of respiratory rise and onset of C_2H_4 production (Figure 4).

Refrigerated Fruit

In a series of four experiments, papayas given the same irradiation doses as in the previous series, except for the highest dose, were studied at 70–77° F after refrigeration at 55° F. Respiration and C_2H_4 studies

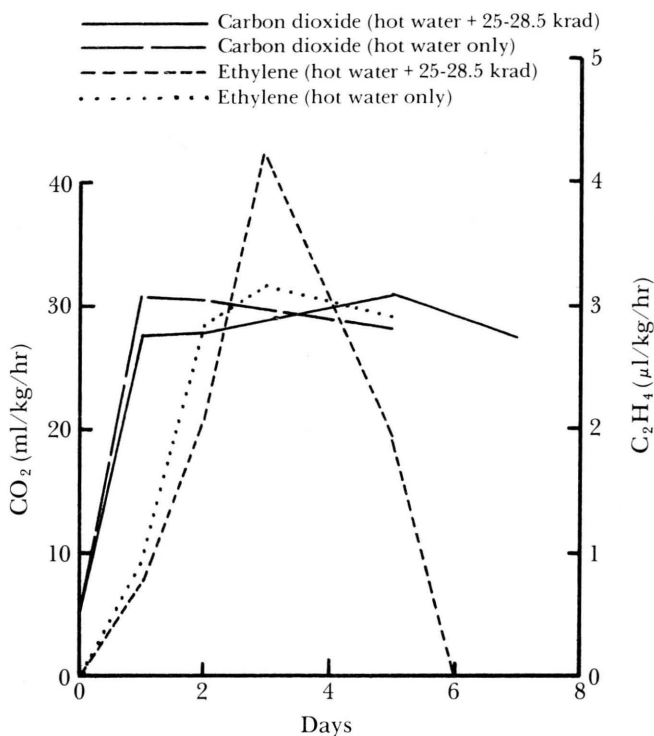


Figure 5. Respiration (CO_2) and ethylene (C_2H_4) production at 77° F in 13 percent yellow papayas hot water treated only or hot water treated and irradiated at 25-28.5 krad, followed by storage initially at 55° F for 7 days then at 77° F.

were conducted on the fruits immediately upon removal from cold storage and daily thereafter.

The first experiment used fruits of about 13 percent yellow color irradiated at 25–28.5 krad. As expected, immediately upon removal from refrigerated storage, CO_2 liberation was very low, and C_2H_4 production was nil (Figure 5). After 1 day at 77° F, CO_2 production increased about six times; and C_2H_4 production had commenced. There was no further increase in respiration after the first day, but C_2H_4 emanation continued to increase, reaching the peak production in 3 days. The respiratory behavior of the irradiated and unirradiated fruits was similar, but the peak for C_2H_4 production was greater for the irradiated fruits (Figure 5). The fruits in the two lots were edible ripe about the third day after removal from cold storage.

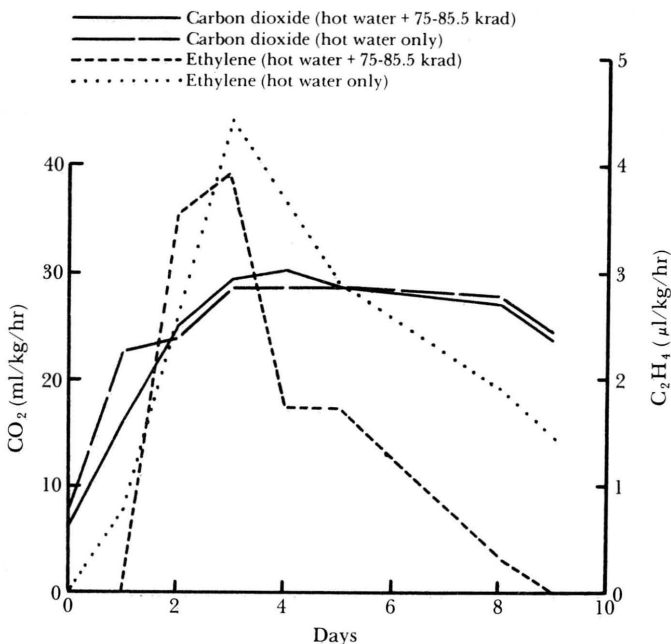


Figure 6. Respiration (CO_2) and ethylene (C_2H_4) production at 72° F in 13 percent yellow papayas hot water treated only or hot water treated and irradiated at 75-85.5 krad, followed by storage initially at 55° F for 7 days then at 72° F.

In the second experiment, papayas of about 13 percent color stage were irradiated at a dose of 78-85.5 krad. After removal from cold storage to 72° F, respiration increased during day 1 (Figure 6) and continued to increase on days 2, 3, and 4, when the peak was reached. The ethylene peak was attained during day 3. In general, respiration and C₂H₄ production were the same for irradiated and unirradiated fruits except that after the peak production, unirradiated fruits

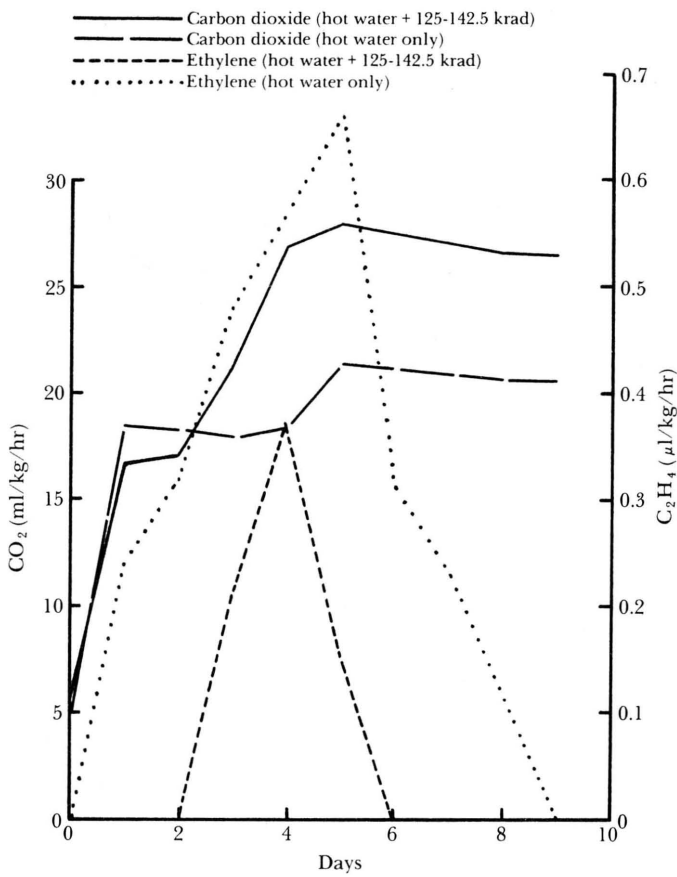


Figure 7. Respiration (CO₂) and ethylene (C₂H₄) production at 70° F in 10 percent yellow papayas hot water treated only or hot water treated and irradiated at 125-142.5 krad, followed by storage initially at 55° F for 7 days then at 70° F.

produced more C_2H_4 . The edible ripe stage of fruits occurred on day 5 for unirradiated fruits and on day 7 for irradiated fruits. The irradiated fruits in this experiment were slightly scalded.

The results shown in Figure 7 concern papayas of about 10 percent yellow stage irradiated at 125–142.5 krad and studied at 70° F after refrigeration (the third experiment). A repeat of this experiment (the fourth experiment) produced similar results (not shown).

The initial maturity of the fruit and the post-refrigeration storage temperature of this third experiment were similar to those of the second experiment, yet the respiratory and C_2H_4 patterns were somewhat different. The respiratory peak was attained about 1 day later in this experiment (Figure 7) than in the previous experiment (Figure 6). The respiratory rate was greater in irradiated papayas than in unirradiated fruits in this experiment (Figure 7), compared with similar respiratory patterns for unirradiated and irradiated fruits when a lower irradiation dose was used (Figure 6). Peak C_2H_4 production for the two lots was attained at the same time in the previous experiment (Figure 6), whereas the peak of the irradiated fruits appeared 1 day earlier than that of the unirradiated fruits in this experiment (Figure 7). The reduction in C_2H_4 emanation due to irradiation was much greater for the higher dose treatment (Figure 7) than for the lower dose treatment (Figure 6). Unirradiated fruits were edible ripe in 5 days and the irradiated fruits in 7 days. The irradiated fruits were scalded.

DISCUSSION AND CONCLUSION

An irradiation dose of 25–28.5 krad is ineffective for delaying the occurrence of the respiratory peak and thus the rate of ripening in unrefrigerated (Figure 1) as well as refrigerated papaya fruits (Figure 5), which confirms the findings of previous investigations (7). These previous investigations established that, even with the optimal dose for shelf life extension (about 75 krad), the rate of ripening is not reduced in fruits with 25 percent or more of initial surface coloration, and this phenomenon is shown again in the present experiment, in which 25 percent yellow fruits irradiated at a dose of 75–85.5 krad attained the respiratory peak on the same day as unirradiated fruits (Figure 2).

Refrigeration reduced the difference in respiratory response between irradiated (75–85.5 krad) and unirradiated fruits with 13 percent initial surface color (Figure 6). However, irradiation delayed the attainment of the edible ripe stage by approximately 2 days.

In papayas irradiated at a relatively high dose of 125–142.5 krad, the appearance of the respiratory peak was delayed in fruits stored at 77° F (Figure 3). When refrigerated at 55° F, the appearance of the respiratory peak was not delayed (Figure 7). In both cases, the attainment of the edible ripe stage was delayed 2 or 3 days. In papayas irradiated at a higher dose of 250–285 krad, followed by storage at 77° F, there was a great delay in the appearance of the respiratory peak (Figure 4), but the fruits were severely injured and failed to ripen normally.

Whether C_2H_4 triggers the onset of the respiratory rise or whether C_2H_4 is merely a by-product of respiration has been of academic interest for some years. Earlier work (8,9) provided no evidence of C_2H_4 being the trigger mechanism for the respiratory rise. In recent years, with the advent of more sensitive instrumentation for C_2H_4 detection, more evidence is being accumulated in support of the concept that C_2H_4 is the trigger (10,11). The relationship between these two physiological processes can be analyzed in the results of the four experiments that were conducted at 77° F. In two of the experiments, in which the fruits were not scalded, the onset of C_2H_4 production preceded by 1 to 2 days the onset of respiratory rise in both the irradiated and unirradiated fruits (Figures 1 and 2). However, in the other two experiments, in which the irradiated fruits were scalded, the two processes coincided in both lots of fruits (Figures 3 and 4). This seems to be an inconclusive evidence that the C_2H_4 may be the trigger for respiration in treated papayas, provided the fruits can tolerate the treatments.

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